Progeny of *Eucalyptus globulus* Labill ssp. *Globulus*

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Abstract: The preliminary assessment of progeny test in a seed orchard of *Eucalyptus globulus* LabilL ssp. *globulus* at Yipinglang State Farm of Yunnan Province in China was conducted. The trial was composed of 21 replications, with 2 trees on each plot, 15 plots in each incomplete block, and 18 incomplete blocks in each replication, laid out in a α- design of 270 open-pollinated families . The families were of three categories (natural populations, local land race and seed orchard). They were further subdivided into 11 regions. The data from an assessment of growth, stem form and other characteristics of the young trees after being planted 2 years were analyzed. Results aro as follows the different categories differed significantly in their growth, with the families from seed orchards being the best. Regions also differed significantly in their growth. The families from the regions of Western Victoria, Eastern Victoria and all three seed orchards were better than others. The families from Yunnan had the best frost tolerant and its survival was the highest. For growth, stem form and fungal tolerance, the families from Yunnan were similar to that from Southern Tasmania and Eastern Tasmania. Two-tree plots were strongly recommended over singletree plot designs for large-scale progeny trials.

Keywords: *Eucalyptus globules*; Progeny trial; Seed orchard

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Introduction

Eucalyptus globulus Labill. ssp. *globulus*, blue gum, is one of the most widely planted eucalypts in the world. The worldwide spread of blue gum was associated with the exploration of southeast Australian in the late 1700s. It is likely that early material of the species was collected in southern Tasmania in the vicinity of Bruny Island and Recherche Bay (Orme 1978). It is believed that an English customs officer introduced it to China in the 1890s from Europe. In 1934, 30-year-old *E. globulus* were found in Kunming, Capital of Yunnan Province, with diameter of 40-50 cm (Wu 1983). Now in China, the tallest eucalypt is an *E. globulus,* which is 40 years old, 49 m high and 110 cm in breast-height-diameter, in Kunming (Qi 2002). Unfortunately, there is no record of origin and parents of these individuals.

Most of the blue gums in China are planted in the Yunnan Plateau, of which Kunming city and Chuxiong city are the center. Blue gum is the principal eucalypt in this area. After 100 years, blue gum has become a component of the forest in Yunnan Province since it was introduced. Blue gum was widely planted along roadsides, in farms as windbreaks, along riverbanks and around houses and it is used as a major afforestation species. This species is adapted to a wide range of soils with high survival percent and good growth rates. Therefore, blue gum has already become a well-adapted land race. The wood of blue gum can be used for fuel wood, mining timber, posts, fiberboard, even furniture and boats, although most trees have severe spiral grain. Recently, blue gum has been recognized as excellent material for pulpwood and rayon in China. Its leaves can be used to extract cineole oil, which is an important product in this area, for medicinal and other purposes.

There is a need for new genetic resources in China. There were about 150 000 hm^2 of eucalypt plantations in Yunnan Province, with an annual planting rate of approximately 10 000 hm^2. Most of them are blue gum. In southwestern Sichuan Province, its cultured area has increased considerably in recent years. After many generations, the local blue gum has been well adapted to Yunnan Plateau and becomes an important gene resource for this area. However blue gum suffers from severe spiral grain that restricts its use for timber products. The spiral grain may be inherited from the initial families or may have resulted from inbreeding, because the initial genetic base for the population was very small. Genetic improvement by tree breeding should be able to reduce the problem. The local genotypes have already been strongly selected by collecting seeds from a small number of the best trees for further plantations. It is impossible to get significant breeding improvement, because inbreeding will prevent improvement in vigor and form. To achieve genetic

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improvement of blue gum in China, we should obtain a broad genetic base from natural stands, and build up the base populations or breeding populations. A suitable breeding strategy must be developed.

There are three other closely related southern blue gums. Kirkpatrick (1974) treated them as one species with four subspecies, *bicostata*, *pseudoglobulus*, *globulus* and *maidenii*. There are few reports about provenance trial of blue gums in China. Provenance trials of blue gum in Yunnan Province showed that *E. globlubus* subspecies *globulus* grew better than the other subspecies *bicostata, maindenii* and *psedoglobulus* (Wang *et al.* 1992). They suggested the natural provenances of *E. globulus* subsp. *globulus* should be used in tree breeding programs. In four-year-old *E. globulus* subsp. *globulus* provenance trials in Yunnan Province, provenances differed significantly in growth rate. The local land race performed better than the natural provenances. None of the natural provenances have been found to have spiral grain; they all have straight bark (Wang *et al.* 1992). From the above, it is known that blue gum is a potential afforestation species in China. So a large-scale progeny trail of *E. globulus* Labill. ssp. *globulus* was focused in this report.

Materials and methods

Study site

The progeny trial of blue gum was established in Yipinglang State Forest Farm (latitude 25°, longitude 102°, altitude 1 800 m), located in the central Yunnan Province, 130 km west of Kunming city. There is a distinct dry and wet season. The wet period is from June to September, while the dry period is from November to April. Mean annual precipitation ranges from 830 mm to 1 000 mm and the annual evaporation is 2 000-2 100 mm. Mean annual temperature is 18 °C and the absolute minimum temperature is -5 °C. Frost occurs occasionally. At the site, mountain red soil is derived from purple shale or purple sandstone, normally more than one meter in depth, with pH value in the range of 4.7-5.2. The soil is well-drained, stone-free, with low to medium organic matter content and compact texture. Soil analysis for bulked soil samples (0-30 cm) at sites is shown in Table 1.

Table 1. Soil properties at trial site of blue gum

Sample No.	pH	Organic carbon (%)	Inorganic components/ $\mu g \cdot g^{-1}$						
			N	P	K	Ca	Mg	Fe	B
1	4.9	1.05	50.1	1.3	99.4	9.2	11.2	7.0	0.18
2	5.2	1.23	78.1	0.9	65.3	5.7	6.3	4.6	0.12
3	4.7	1.22	50.1	11.1	40.2	22.9	23.0	1.8	0.4

On the Yunnan Plateau, the forest type is of evergreen broadleaved forest. The major species included *Quercus* and *Castanopsis*, and some mixed pine-oak forest type at relatively high altitudes, composed of *Pinus yunnanensis Franch* and *Quercus*. This area is mountainous with little flat land. The study site was set on the high-middle slope of a hillside. It is representative of the main areas that will be used for blue gum plantations.

Genetic materials

A total of 270 seedlots were used in the trial. Each of them was collected from one single mother tree. So the seeds from one seedlot were open-pollinated families with unknown fathers. We call them half-sib families. The seedlots, which are from different source and region, are grouped into three categories. Subdivision of Categories allows the identification of 11 regions based on seed collection regions:

Category 1: natural stands in Australia.

Region 1: West coast Tasmania (WT), 22 seedlots;

Region 2: Eastern Tasmania (ET), 36 seedlots;

Region 3: Southern Tasmania (ST), 39 seedlots;

Region 5: Bass Strait Islands (BSI), 42 seedlots;

Region 6: Western Victoria (WV), 44 seedlots;

Region 7: Eastern Victoria (EV), 11 seedlots;

Region 11: Wilsons Promontory (WP), 9 seedlots.

Category 2: seed orchards in Australia, Portugal and New Zealand.

Region 4: Tasmania seed orchard in Australia (TSO), 20 seedlots;

Region 8: Portugal seed orchard (PSO), 32 seedlots;

Region 9: New Zealand seed orchard (NSO), 1 seedlots.

Category 3: local land race in Yunnan Province.

Region 10: Yunnan Province in China (YP), 14 seedlots.

Trial design

A randomized incomplete block design—α -design (John 1987) generated by ALPHA+ package (Williams *et al.* 1994) was used for the trial.

Twenty-one complete replications were used in the trial. Only 19 replications were used in the analysis for other two with too much missing plots after plantation. There are 18 blocks within one replicate, which includes all 270 seedlots. Two-trees plot was used. The blocks were line sections with 3 m between lines and 1.5 m between trees along the lines, giving a plot size of 3 m × 3 m, an incomplete block size of 3 m×45 m and replicate size of 54 m×45 m. The blocks were laid out with their long axis at right angles to the main (down slope) environmental field trend.

Measurements

Eight variants of tree height (H), diameter at breast height (DBH), crown width in east-west (CEW), crown width in north-south (CNS) and tree survival (SVL) were measured.

Stem form (STM), fungal tolerance (FGL) and frost tolerance (FST) were determined using simple subjective scoring systems. Three degrees were used to describe STM. "2" means the tree with a straight stem. "1" means the tree with curve or slant stem. "0" means the tree with more than one main stem. Also three degrees were used to describe fungal tolerance. "2" means the tree without fungal damage. "1" means the tree with fungal damage. "0" means the tree with serious fungal damage. Two degrees were used for frost damage. "0" means the tree without frost damage. "1" means the tree with frost damage. The data were analyzed by orthogonal analysis of variance (ANOVA).

Analysis

The analysis was separated into two steps by GENSTAT package. This two-stage method has been suggested by Williams and Matheson (1994). The first stage use FIT (fixed-effects model) command to analysis variance components of seedlots and environment, and expected methods of the seedlots were estimated for the second step. The model of FIT analysis is as follows:

$$Y_{igh}=\mu+\rho_i+\beta_{ig}+\tau_j+\varepsilon_{igh} \quad (1)$$

Where, the Y_{igh} ($i=1, 2, \ldots, r$; $g=1, 2, \ldots, s$; $h=1, 2, \ldots, k$) is the observation (average of two trees in one plot) for $r=19$ replicates each with $s=18$ incomplete blocks containing $k=15$ plots; μ is a parameter for the overall mean; the ρ_i, β_{ig} and τ_j are parameters for replicates effect, incomplete blocks effect and seedlots effect respectively; and the ε_{igh} is residuals in the model.

The second stage is to group the seedlots into category and region structure. Further analysis on estimated seedlot methods was carried out with ANOVA (analysis of variation) command of GENSTAT and the nested structure was used in the analysis. The model is as follows:
(seedlot effect) = (category effect) + (region effect) + (family effect).

Results

Difference of categories, regions and families

Categories

The significance tests for category, region and family are shown in Table 2. The estimated category and region methods are shown in Table 3.

The progenies of category were significantly different in height, DBH, crown size, stem form and fungal tolerance (Table 2). There was no significantly different in frost tolerance between the progenies of category. From the characteristics of H, DBH, CEW and CNS, it can be seen that the growth of the seed orchard categories is better than that of the natural categories and local land race. For example, the height of SO is 7.90% higher than that of NATURAL and 5.36% higher than that of LOCAL. Especially the trees from SO have larger crown size than that from NATURAL and LOCAL. Larger tree crown size indicated the tree had strong competition capacity in light and other factors. Larger crown size of young tree lays a good material basis for later growth. For fungal tolerance, the local land race and seed orchard selections were better than natural resources. For frost tolerance and survival, the local land race was better than natural resources and seed orchard selections. That means it is well adapted to the local environment after one hundred years.

Table 2. *F*-value of significance tests for category, region and family

Characteristics	Category	Region	Family
Tree height	43.41*	81.05*	3.54*
Diameter at breath height	12.91*	28.52*	3.68*
Crown width east-west	49.02*	28.14*	2.38*
Crown width north-south	49.64*	29.58*	2.51*
Stem form	8.98*	19.92*	2.42*
Fungal tolerance	5.87*	17.82*	2.57*
Frost tolerance	1.30	4.80*	1.80*

Notes: * ---- significant different at α =0.01.

Regions

All the variants showed significant differences between regions within categories. From the characteristics of H, DBH, CEW and CNS, it can be seen that the growth of the families from western Victoria, eastern Victoria and all the seed orchards was best, followed by East Coast of Tasmania, Yunnan Province, southern Tasmania and Bass Strait Islands. West Coast Tasmania was inferior in growth and Wilsons Promontory was the worst. For stem form, all the seed orchards were best. For fungal tolerance, Wilsons Promontory was best; eastern Victoria was second and the Bass Strait Islands worst (Table 3). For frost tolerance, Yunnan Province was the best, and eastern Victoria and Wilsons Promontory were worst. For survival at 2 years, Yunnan Province was the best, and western Victoria, New Zealand seed orchard and Wilsons Promontory the worst.

Families

Significant differences between families within regions were found in height, diameter at breast height, crown size, stem form, frost tolerance and fungal tolerance (Table 2). There is genetic diversity not only between categories and regions, but also between families within region. It means the selection between the families within region is still necessary for the further breeding procedure. However, it is not more important than categories and regions, especially regions for us to select the seeds. It can be found by *F*-value of the three structures. *F*-value of the regions and the categories is much more than those of families and the *F*-value is almost linear related with variance component of each structure.

Two-tree plot design

In the first year, tree number survival percent was 91.2%. It decreased much to 79.6% in the second year. The total designed plots survival percent was 98.5% in the first year and 92.3% in the second year. Plots survival rate was much

higher than that of tree survival. So, the number of missing two-tree plots was much lower than that of singletree plot. This is very important for the statistical analysis of progeny trials.

Table 3. Characteristics means of different categories and regions

Item		H/m	DBH/cm	CEW/m	CNS/m	STM	FGL	FST	SVL (%)
	Natural	1 786	1.236	1.046	1.065	1.082	1.376	0.239	80.43
Category	SO	1.927	1.325	1.136	1.156	1.133	1.411	0.241	82.22
	Local	1 829	1.266	1.021	1.034	1.101	1.439	0.264	85.63
	WT	1.656	1.060	0.948	0.967	1.008	1.349	0.243	78.49
	ET	1.840	1.291	1.064	1.082	1.106	1.429	0.261	82.25
	ST	1.808	1.254	1.045	1.068	1.098	1.418	0.239	82.72
	TSO	1.947	1.361	1.133	1.148	1.122	1.367	0.231	82.56
	BSI	1.738	1.256	1.055	1.076	1.111	1.270	0.254	83.19
Region	WV	1.934	1.303	1.106	1.118	1.094	1.357	0.234	75.89
	EV	1.963	1.362	1.097	1.133	1.163	1.446	0.183	81.06
	PSO	1.914	1.297	1.139	1.161	1.137	1.437	0.248	82.73
	NSO	1.942	1.505	1.110	1.149	1.252	1.438	0.230	73.68
	YP	1.829	1.266	1.021	1.034	1.101	1.439	0.264	85.63
	WP	1.089	0.803	0.829	0.827	0.802	1.561	0.160	72.65

Notes: Category includes: Natural stands in Australia; SO---- Seed orchards; Local land race in Yunnan Province. Region includes: WT---- West Coast Tasmania; ET---- Eastern Tasmania; ST---- Southern Tasmania; TSO---- Tasmania Seed Orchard; BSI----Bass Strait Islands; WV---- Western Victoria, EV---- Eastern Victoria; PSO---- Portugal Seed Orchard; NSO----New Zealand Seed Orchard; YP----Yunnan Province; WP---- Wilsons Promontory.

Discussion

Height, DBH and crown size are the characteristics for growth of trees. The families from seed orchards had the best growth, probably because the breeding improvement has already been achieved by selection of good growth performance and by reduction of inbreeding compared with those in natural stands.

The families from eastern and western Victoria were the best provenances in natural stands for growth and were similar to the families from seed orchards. The families from seed orchards had already been selected in Tasmania, Portugal and New Zealand. For further breeding improvement, eastern and western Victoria should be the best source of material, because of their good growth without artificial selection.

The families from the local land race in Yunnan Province were better than those in Tasmanian natural regions, but worse than western Victoria and eastern Victoria. Blue gum has been selected by the local environment and by people for good growth for about 100 years. However, the Yunnan land race was always very similar to or a little better than that in eastern and southern Tasmania, but much better than that in western Tasmania and quite different from Victoria in height, DBH, crown size and stem form (Table 3). The limited historical evidence and the similarity of the performance of the Yunnan and eastern and southern Tasmania families suggest that the Yunnan land race origin from southern or eastern Tasmania.

Yunnan Province has heavier frost than the natural environments of blue gum. After 100 years, the land-race has become adapted to this environment by natural and artificial selection. So it showed better frost resistance and survival. Although the growth and stem form were not better than that of families from seed orchards or eastern and western Victoria, the land race is still an important base population for good frost tolerance and survival rate.

Wilsons Promontory was the worst region with the worst provenances and the worst families in growth, stem form, frost tolerance and survival rate. However, it was the best region for fungal tolerance.

The introduced germplasm resources of blue gum were rich in genetic biodiversity from the above results. It is the best base population for genetic improvement of blue gum in China.

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